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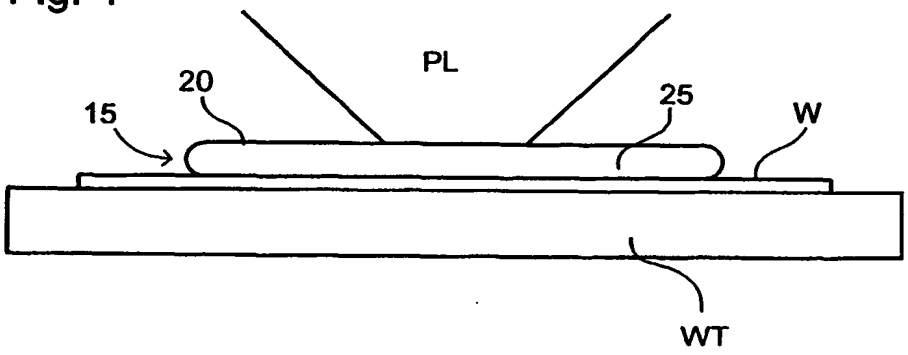
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Remarks:
Claims 11 and 12 are deemed to be abandoned due to non-payment of the claims fees (Rule 31 (2) EPC).

(54) Lithographic projection apparatus and device manufacturing method

(57) To improve the resolution of lithographic apparatus a sack member is placed between the projection system and the substrate. The sack member can be filled with a fluid of a known refractive index. The sack member should be in contact with both the projection system and the substrate.

Fig. 4



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Description

[0001] The present invention relates to a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate; and
- a projection system for projecting the patterned beam onto a target portion of the substrate.

[0002] The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described hereabove, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.
- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as hereabove set forth.

[0003] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus —commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More in-

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formation with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

[0004] In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

[0005] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

[0006] It has been proposed to immerse the substrate in a lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective NA of the system.)

[0007] One of the proposals is to submerse the substrate or substrate and substrate table in a bath of liquid (see for example US 4,509,852, hereby incorporated in its entirety by reference). However this means that there is a large body of liquid that must be accelerated during a scanning exposure. This requires additional or more powerful motors and turbulence in the liquid may lead to undesirable and unpredictable effects.

[0008] An alternative solution is for a liquid supply system to provide liquid in a localized area between the final element of the projection system and the substrate (the substrate generally has a larger surface area than the final element of the projection system). One way which has been proposed to arrange for this is disclosed in WO 99/49504, hereby incorporated in its entirety by reference. As illustrated in Figures 2 and 3, liquid is supplied by at least one inlet IN onto the substrate, preferably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet OUT after having passed under the projection system. That is, as the substrate is scanned beneath the element in a -X direction, liquid is supplied at the +X side of the element and taken up at the -X side. Figure 2 shows the arrangement schematically in which liquid is supplied via inlet IN and is taken up on the other side of the element by outlet OUT which is connected to a low pressure source. In the illustration of Figure 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and numbers of in- and out-lets positioned around the final element are possible, one example is illustrated in Figure 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element to form a liquid reservoir.

[0009] Another solution which has been proposed in European patent application no. 03252955.4 is to provide the liquid supply system with a seal member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. The seal member is substantially stationary relative to the projection system in the XY plane and a seal is formed between the seal member and the surface of the substrate. Preferably the seal is a contactless seal such as a gas seal.

[0010] However, to confine the fluid to a localized space beneath the projection system (as in the last two proposals) the space must be small which can be difficult to construct and incorporate all the required features e.g. alignment. All of the above proposals could cause coupling between the substrate table and projection system leading to vibration in the projection system. The presence of free liquid could cause problems for other elements within the system. In particular if a crash occurred between the substrate table and the projection system localized fluid solutions would be destroyed and dispersed throughout the apparatus potentially damag-

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ing intricate electronics. Furthermore, in some localized fluid solutions the substrate table can only be scanned in a particular direction, severely limiting the application of these proposals.

[0011] It is an object of the present invention to provide an alternative lithographic apparatus and method which allows the resolution to be improved without some of the disadvantages of having free immersion liquid.

[0012] This and other objects are achieved according to the invention in a lithographic apparatus as specified in the opening paragraph, characterized by a flexible member arranged between a final element of said projection system and said substrate, said flexible member having a refractive index higher than air.

[0013] The flexible member allows the resolution to be improved without the presence of free immersion liquid. The substrate table can be scanned in any direction and there is no possibility of the immersion liquid being dispersed through the system due to a crash and damaging delicate parts of the apparatus.

[0014] The flexible member is optionally a sack or balloon filled with fluid. The sack thus confines the localized liquid and avoids fluid dispersion in the case of apparatus error. For optimal results the sack can be closed to the environment, and the fluid should be a liquid, for example it should be substantially water.

[0015] To ensure uniform and reliable transmission the flexible member can be in contact with the final element of the projection system. Similarly when there is a substrate on said substrate table said flexible member can be in contact with said substrate to avoid any optical errors or evanescent fields developing.

[0016] The inventors have found sacks comprising Teflon, fluorinated hydrocarbon polymers or polyfluoride to be particularly suitable for this invention. The sack member can have a thickness of 1μm to ensure sufficient flexibility of the member. Further, at least a part of the flexible member can be transmissive to the projection beam.

[0017] The flexible member should be sufficiently flexible to be deformable by the relative movement of the projection system and the substrate table.

[0018] According to a further aspect of the invention there is provided a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

characterized by providing a flexible member arranged between the final element of said projection system and said substrate.

[0019] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

[0020] In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (*e.g.* with a wavelength of 365, 248, 193, 157 or 126 nm).

[0021] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;
Figure 2 depicts a liquid supply system according to the prior art;
Figure 3 is an alternative view of the liquid supply system of Figure 2 according to the prior art; and
Figure 4 depicts a detail of a lithographic projection apparatus according to an embodiment of the invention.

[0022] In the Figures, corresponding reference symbols indicate corresponding parts.

[0023] Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

- a radiation system Ex, IL, for supplying a projection beam PB of radiation (*e.g.* DUV radiation), which in this particular case also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (*e.g.* a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (*e.g.* a refractive system) for imaging an irradiated portion of the mask MA onto a target portion C (*e.g.* comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (*e.g.* has a transmissive mask). However, in general, it

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may also be of a reflective type, for example (*e.g.* with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

[0024] The source LA (*e.g.* an excimer laser) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

[0025] It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

[0026] The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

[0027] The depicted apparatus can be used in two different modes:

In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;

In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

[0028] Referring to Figure 2, below the projection lens PL is a flexible member 15 with a refractive index higher than the surrounding environment. The flexible member 20 covers a slightly larger area than the final element of the projection system PL and is preferably a sack 20, a balloon or a membrane filled with fluid 25. The sack 20 comprises a thin flexible material which is transmissive to the projection beam. For example, sacks 20 comprising polyfluoride, fluorinated hydrocarbon polymers or Teflon have found to be particularly suitable. The sack material is approximately 1μm thick such that the shape of the member 15 can be determined by the surrounding forces and the thickness of the sack is negligible compared to the size of the sack. The sack material has a refractive index approximately equal to the refractive index of the fluid 25; the refractive index should be between 1 and 2. The sack 20 is preferably completely filled with liquid 25, leaving no gas bubbles ensuring uniformity of exposure. Alternatively a homogenous gas 25 could fill the sack. The fluid 25 used should have sufficient density such that the shape and movement of the member 15 is primarily determined by the properties of the fluid 25 rather than the sack. For example, the fluid 25 should be sufficiently dense that the member 15 takes on a cylindrical shape (of small depth) rather than a spherical shape. The fluid 25 used should be transmissive to the projection beam and have a refractive index higher than the surrounding vacuum or gaseous atmosphere. The flexibility of the member 15 and the fluidity of the fluid 25 is such that the member 15 is deformed by the relative movement of the projection system PL and the substrate W.

[0029] The sack is sandwiched between the final element of the projection system PL and the substrate. The member 15 should preferably be in contact with the final element of the projection system PL and the target portion C of the substrate W during exposure

[0030] According to a first embodiment of the invention the sack 25 is an open sack: it is open on either or both of the side of the projection system PL or the substrate W. It is however mounted onto the projection system PL and as the substrate table WT is moved, either in step or scan mode, the member 20 remains at the focal point of the projection system PL. In this embodiment the water can be refreshed between each exposure, or the immersion fluid 25 can be topped up to en-

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sure the sack 20 remains full.

[0031] According to a second embodiment of the invention the sack 25 is a closed sack. This embodiment is particularly applicable to apparatus used in the step mode. The substrate W is aligned in the X and Y directions beneath the projection system PL and member 15. Prior to exposure occurring the substrate table WT is moved a small distance in the Z direction to bring the substrate W into contact with the member 15 and into the focal plane of the apparatus. After exposure the substrate table is moved down in the Z direction and aligned for the next exposure.

[0032] A lubricant is provided between the final element of the projection system PL and the member 15 to aid smooth movement. The member 15 could also be slid under the projection system PL i.e. require no movement of the substrate table WT in the Z direction.

[0033] Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

Claims

1. A lithographic projection apparatus comprising:

 - a radiation system for providing a projection beam of radiation;
 - a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
 - a substrate table for holding a substrate;
 - a projection system for projecting the patterned beam onto a target portion of the substrate,

 characterized by a flexible member arranged between a final element of said projection system and said substrate, said flexible member having a refractive index higher than air.

2. A lithographic projection apparatus according to claim 1 wherein said flexible member is a sack filled with fluid.

3. A lithographic projection apparatus according to claim 2 wherein said sack is closed to the environment.

4. A lithographic projection apparatus according to either claim 2 or claim 3 wherein said fluid is a liquid.

5. A lithographic projection apparatus according to claim 4 wherein said liquid is water.

6. A lithographic projection apparatus according to any one of the preceding claims wherein said flexible member is in contact with said final element of the projection system.

7. A lithographic projection apparatus according to any one of the preceding claims wherein when there is a substrate on said substrate table said flexible member is in contact with said substrate.

8. A lithographic projection apparatus according to any one of claims 2 to 7 wherein said sack is comprised of Teflon or polyflouride.

9. A lithographic projection apparatus according to any one of claims 2 to 8 wherein said sack member has a thickness of 1μm.

10. A lithographic projection apparatus according to any one of the preceding claims wherein said flexible member is deformable by the relative movement of the projection system and the substrate table.

11. A lithographic projection apparatus according to any one of the preceding claims wherein at least a part of the flexible member is transmissive to the projection beam.

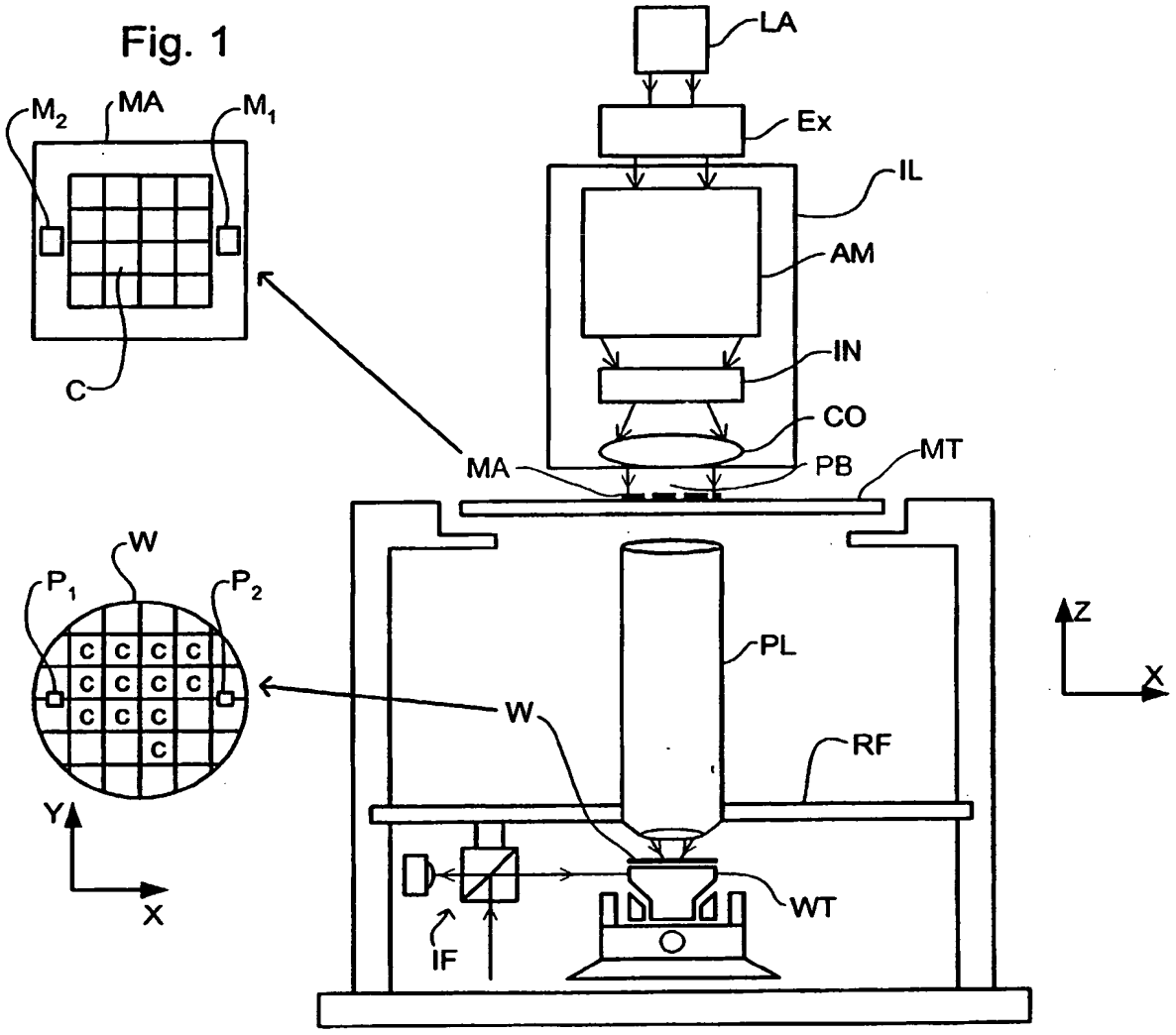
12. A device manufacturing method comprising the steps of:

 - providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
 - providing a projection beam of radiation using a radiation system;
 - using patterning means to endow the projection beam with a pattern in its cross-section;
 - projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,

 characterized by providing a flexible member arranged between the final element of said projection system and said substrate.

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Fig. 1



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Fig. 2

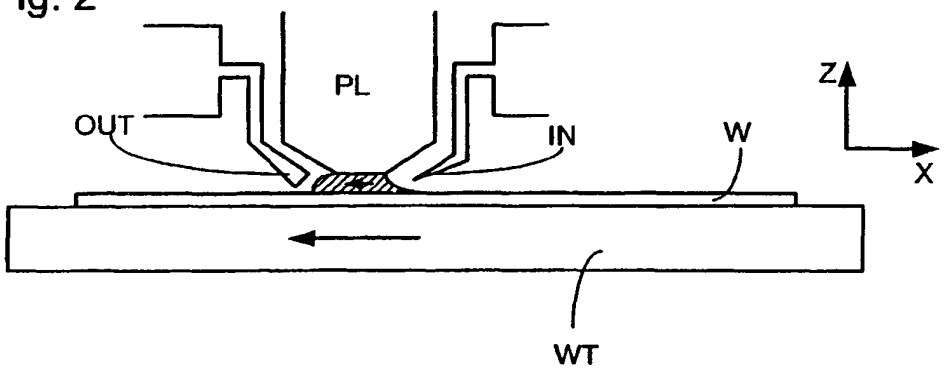


Fig. 3

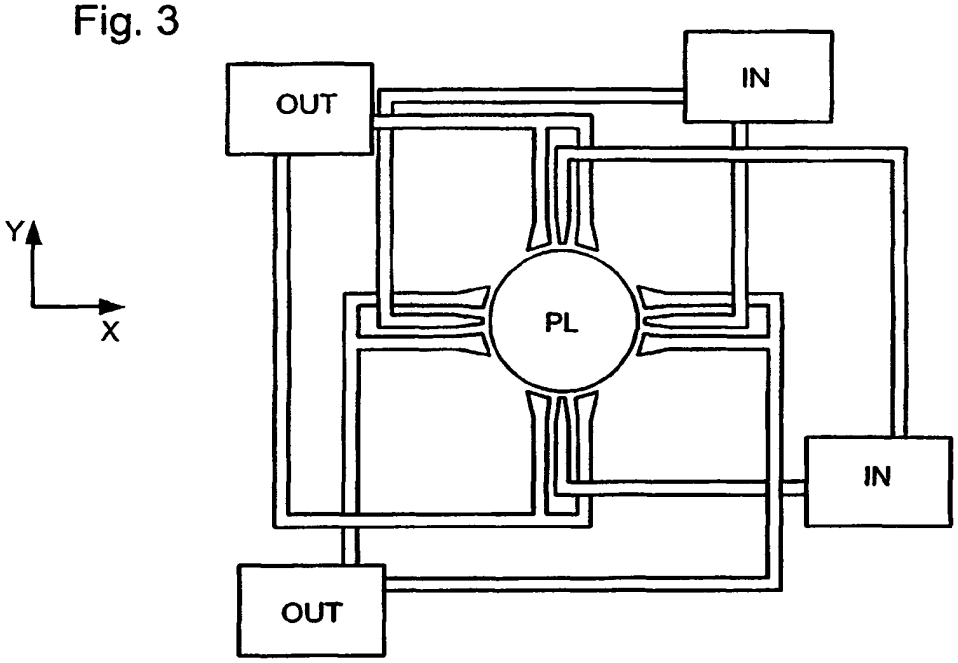
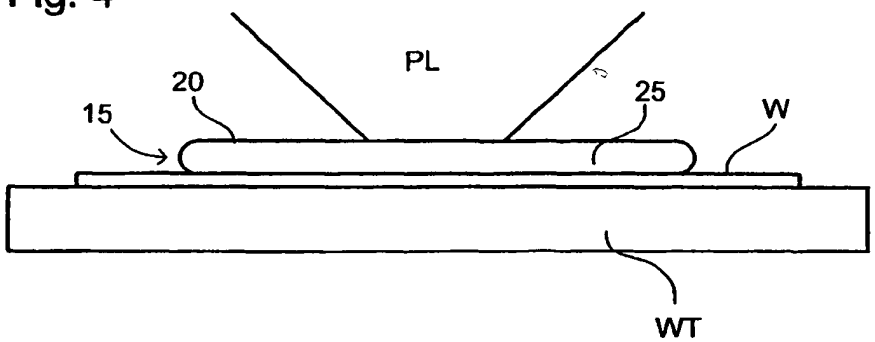


Fig. 4



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EUROPEAN SEARCH REPORT

Application Number
EP 03 25 4143

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	7 May 2004	van Toledo, W

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 03 25 4143

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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